Problem Framing in Multiple Settings

Thomas Kvan and Song Gao

This study offers an insight to architectural students' problem framing activities using digital and paper media. The role of problem framing in design processes and its contribution to design learning has been studied by others. Here, we investigate the effects of media on framing activities. Laboratory experiments were conducted to investigate problem framing under three settings, namely online co-located, online remote and paper-based co-located. Student pairs were asked to spend forty minutes in solving collaboratively a wicked design problem. The results show that problem framing activities are significantly different in the online remote setting compared to those in the two co-located settings. We find more density of framing activities happened in the online remote setting than in the other two settings while there is no significant difference between online co-located and paper-based co-located settings.

1. Introduction

Design problems have been categorized as well-defined, ill-defined or wicked, reflection the extent to which their solutions are immediately apparent [1]. The issue of wicked problem was first dealt with in the 1960s and 1970s [2, 3], challenging the traditional linear method of problem solving. Design processes are the processes of problem solving, which have been explored extensively and described according to features of these different categories of design problems [4-6]. Common in these studies we find the activity of problem definition being applied to transform ill-defined or wicked design problems into well-defined. In particular, Schön's cyclical design process, which he describes as a "reflective conversation with the material of the situation", has been extensively used in research into design education and design activities. Schön has referred to the act of problem definition as "problem framing", the term we will use in this paper. He postulated that the activity of framing was central to a successful process of design and hence is a key activity in design.

Paper-based sketching helps designers engage in the design process, in significant part so that designers can frame problems effectively [7, 8]. Digital based design tools have gained prominence in design processes but have typically been used in discrete problem solving processes or in presentation of work. Although some architects suggest that the potential of digital representation challenges convention representation fundamentally, without which designers will not exceed the paradigm of the Renaissance world view [9], others conjecture that digital tools inhibit communication between the designer's mind and hand, interrupting the design "conversation" [10]. Designers are often reluctant to use digital tools to 'aid' them in this creative and cyclical design process. This attitude has also influenced the teaching of design and hence use of digital tools in architectural education beyond simply use as skill building tools.

The assumption that digital tools interrupt the design conversation is not supported by earlier research. Previous studies have shown that digital tools can afford high level communication including 'frame' and 'reflection', which contributes to successful design and design learning [11]. The question examined in this research, therefore, is whether the use of digital tools inhibits the "conversation" by reducing problem framing activities specifically.

This research was carried out by observing pairs of postgraduate students in solving the same problem under different conditions. Teamwork process-based protocol analysis was utilized to compare the design activities of postgraduate students using different design tools in different design settings. A coding scheme was developed from Schön's model of design process. The design task, which has been used in previous studies [11], requires these students to spend forty minutes in solving a real world, wicked design problem. Three settings were set up: online co-located, online remote and paper-based co-located. In this paper we apply the coding scheme to isolate the activities of framing, report the results and discuss the findings.

2. Literature Review

While well defined problems are solved by relatively straightforward processes, the solution of ill defined or wicked problems is central aspect of research in creative design [2, 12]. Thus, the activities in solving such problems is a valuable focus of effort in the domain of design research [1, 5, 13, 14].

It is suggested that there are two kinds of knowledge, "procedural knowledge" and "substantive knowledge", intertwined and related during designing [1]; Schön has called these activities "knowing how" and "knowing that". In his description of Simon's "know how", Rowe distinguishes such design activities as "purposefully planning", while Schön's "know that" is the design activities of "engagedly conveying".

Design is a form of functional interpretation and the duty of an architect is to bring order to the world [13]. Mitchell's approach is a design activity that is "planned" to satisfy the functional requirements and the form of compositions by utilizing design rules such as types and vocabularies. The procedure of 'manipulation' or 'planning' is a heuristic search in which the size of the problem spaces is reduced through decomposing design problem into several sub-problems [5]. Simon suggests that such a search could be automated using artificial intelligence, with systems that are "not only ... capable of discovering new concepts but also they can plan sequences of experiments, postulate reaction paths for complex chemical reaction, induce rules for interpreting data from mass spectrogram analysis, and enlarge the state space of a system to accommodate variables that are not directly observable" [5]. In such an expandable search process, the problem is redefined and re-conceptualized.

Design, however, not only consists of the manipulation of existing objects but also the "inventive science … which has not subject matter aside from what the designer conceives it to be" [14]. This step of conception belongs in the act of framing, where the designer creates an understanding where none exists. Two important facets are involved therefore in solving wicked problems: first is to conceive a new problem: 'a working hypothesis', second is to access the knowledge across disciplines to relate a novel solution.

2.1. Problem framing

Previous design studies have described problem framing by adopting different terms. Goldschmidt [15] suggests problem representation as a process of acquiring problems from given information. She finds that problem representation plays an essential role during the process of designing. Kolodner and Wills [16] indicate that problem reformulation could prevent designers from being trapped into "default assumptions about the constraints of the problem" and assist designers to create new criteria and constrains. Cross and Cross [17] claim that problem framing is to "frame the problem in a distinctive and challenge way" and notice that it an important aspect of design strategy adopted by outstanding expert designers. Cross [18] explains design as exploration since designers accept design brief as a part of "unknown territory" and start to explore and discover something new rather than to return with something already existing. Geol and Pirolli [19] describe problem framing as problem structuring: because of the ill-defined problems designers need to establish and transform problem parameters before the starting of problem solving. They indicate that although problem structuring activities occur mainly at the beginning of design project, they reoccur periodically as needed during the process of designing. Cross [20, 21] makes a comprehensive review on problem framing, leading this issue to be more distinct in design studies.

The design theories discussed above do not define the activity of problem framing explicitly yet all imply such an activity of identification. Every theory acknowledges that the act of designing is predicated upon a 'problem' being identified. Thus, in each of the formulations of the design process, a significant and necessary step occurs when a problem is changed from one that is vague, unsolvable or wicked into one that can be addressed with appropriate design knowledge or processes. This cognitive activity has been identified variously as redefinition, re-conceptualization or re-hypothesizing. It is this act that Schön called 'framing'.

> As [inquirers] frame the problem of the situation, they determine the features to which they will attend, the order they will attempt to impose on the situation, the directions in which they will try to change it. [22]

Schön [12] analyzed the activities of problem framing happened in design studio on observation of Quist (a master) and Petra (a student). The design problem Petra faced was to try to fit the shape of the building she designed to the slope of the site, but she failed, which led her feeling 'stuck'. Quist reframes this problem by beginning with a principle that "coherence must be given to the site in the form of a geometry". Quist implied Petra could try a new geometry by "making the knowing the violation of the initial geometry" as he then demonstrated by means of a series of sketches. These sketches as "on-the-spot drawing experiment "illustrated his way of reframing this problem. Quist continued identifying new design problems (environment problem, sunlight problem, circulation problem, etc.), working his way through stages described by Schön as "framing, moving, and reflection", suggesting a cyclical design process that steps through these three stages. An analysis of the process by which Quist framed the first design problem in Schön's example might help us understand problem framing activities:

Examples of 'problem framing'		An example of design problem
"Set its boundaries"	:	"A principle" – 'starting from a geometry form'
"Select particular things and relations for attention"	:	"L-shaped classrooms and orientation of them, etc."

As shown above the cyclical design process involves three key elements, namely "framing", "moving", and "reflection", which are expressed using the design language: talking and drawing [6, 12]. In this description, "framing" is located at the first part of this cycle, while "moving", an exploratory activity, depends on this "framing". "Reflection", which is that the designer allows the situation to talk back, permits a new way to see things, causing a new design cycle to be initiated going through "reframing", "removing", and "reflection". This model has been adopted by others in studies of design education and design media and serves well as a basis for the research reported here.

2.2. Framing, fixation and learning

Problem framing not only is an essential element in the design process, but plays an important role in design learning as well [23-25]. Schön has categorized design as a reflective conversation [22]. Dewey points out five essential functions of reflective activity: suggestion; intellectualization; hypothesis; reasoning; testing the hypothesis by action [23]. Although his concept of reflection has made a unique impact on education and influenced next generations [26], his description of the five activities is problematic. The first phrase, suggestion activity, tends to lead people to have possible solution (pre-conception) directly in their minds. Although he suggests that the sequence of the five phrases is not fixed, he did not clearly define that reflection engages an interactive or dialectical process, therefore the sequence of these activities is ambiguous.

Building upon Dewey's theory, Schön seems to solve this problem, and develops the cyclic design process of design [26]. This design process is also a learning process [25]. Through this process architectural students re-represent design problems by looking at these problems in different ways, therefore prevent them being stuck on early design solutions, thus enhancing their design learning [27, 28]. Sachs claims that the most common method for "getting unstuck" is to seek help and try to see the design in a new way [27]. Kvan [28] suggests that the re-representations of design concepts and solutions has the potential to support students design learning.

Argyris provides three reasons to identify learning [24]. The first reason is to learn is to close the gap between our stored knowledge and the knowledge required to act effectively in a given setting. The second is a continual need to monitor our intention and implements that become an iterative process required learning as well. The third is the necessity to codify these effective actions to make them explicit.

> Learning occurs when we detect and correct error. Error is any mismatch between what we intend an action to produce and what actually happens when we implement that action. It is a mismatch between intentions and results. Learning also occurs when we produce a match between intentions and results for the first time. [24]

He describes two models of the organizational learning, single-loop learning and double-loop learning. Single-loop learning is the model adopted by many professionals to defend themselves routinely, which prevents them from continuously learning and change, while the double-loop learning is the model that could help professionals enhances their competences. The main difference of both learning models is located at the first part that is governing variables to bridge the knowledge gap.

The governing variables are identified by Argyris as master programs. Since these master programs are a set of values which actors choose to guide their intended consequences, they are similar with the concepts of problem framing. Through framing students can drive stored knowledge into action, the gap can be filled and learning occurs. Thus, in the field of learning theories the activities of problem framing has the potential to enhance students' design competence.

2.3. Contribution of media to problem framing

Sellen and Harper have identified the contribution of media and their deployment to cognitive activities in knowledge work [29]. Designers use a variety of media in design activities such as sketching, drawing, and modeling to generate ideas, explore problems and identify solutions. Media as external representations assist designers to structure problem space so as to transform design problems from wicked or ill-defined to well-defined. Through adopting representational tools, designers articulate emerging knowledge in durative media.

Schön's description of design conversation happened in the studio is in paper based co-located setting in the form of face-to-face communication [12]. Paper based design tools have been dominant in studio teaching since the formalization of design learning in the Ecole des Beaux Arts. Indeed, the advent of the use of paper in designing has been noted as the moment at which design became an intellectual activity [30]. For many designers, the medium is inextricably bound into the activity of designing, with designers largely using paper-based sketches to explore and then frame design problems [31]. Although compared to digital design tools paper seems to offer more predictability, therefore afford more communication, paper can only take effect in co-located setting [29].

Digital design tools have been implied to inhibit communication between mind and hand because of the inappropriate precision demanded by the system, interrupting the conversation of design [10, 32]. Interviewing several architects, Lawson found that most of them preferred using paper based design tools to help them in design thinking, then using digital tools for documentation and presentation rather than as part of design process [32]. Corona-Martinez and Quantrill observe the computer is not a drawing instrument like a pencil but engages the designer in a different relationship with the act of drawing, changing the act with "an intermediate system of drawing according to our indications provided by the pressure on the button of mouse, which in turn responds to the feedback from our sight of what appears on a screen … something new has invaded the apparently intangible craftsmanship of drawing" [10].

Not all writings however suggest a negative impact of digital technology on design. It has been widely recognized that designers can carry out their work in geographical distributed locations with the aid of digital tools. This particular affordance provided by the new tools is one that paper lacks, even with access to a fax machine. Yet other benefits have been identified. Previous studies have examined the effects of digital representational tools on design process and learning. Kvan [11] explores the effects of low (Chat-line) and high (Video conferencing tools) band width of collaborative design tools on design communication and find that the textual supported computer tools (chat-line) facilitated more high level communication. Gabriel and Maher [33] study the design communication with computer and without computer mediated environments. Adopted the coding scheme created by them, they find positive aspects of computer mediation in design process. Schnabel and Kvan [34] further explore the influence of 3D modeling design tools(immerse vs. desktop) supported by chat-line communication. They found that immersive design tools with chat-line communication facilitated designers' spatial understanding better than desktop-based tools. While the three studies above have been carried out in laboratory experimental conditions, other recent studies have examined the impact of the digital communicational tools on design learning in real world projects; these results show that digital tools can support students or designers exploring and discovering more high level design ideas compared to conventional communicational tools (paper-based face-to-face environment), thus leading to successful design and learning [28, 35-37].

2.4. Summary

The importance of problem framing in designing and learning has been elucidated above. In this process, designers use design representational tools as means to articulate their expertise and knowledge when exploring the problem space, thus translating a problem from the realm of wicked problems into that of the well defined, such that a solution can be found after iterations of reformulation and searching.

To critically address these proposals, however, we need to extend our understanding of design processes. To contribute to this discovery, we wish to identify whether digital processes bring any changes into the conventional design process. In particular, we wish to identify whether the tools disrupt problem-framing activities and thus inhibit students' design learning. It is on this basis that we conducted our experiments.

3. Laboratory experiments

In this study we carried out laboratory experiments to compare the activities of designers in paper-based and digital-based studio settings. In order to make these settings comparable, we choose Microsoft Net-meeting including whiteboard and chat line as digital design tools and paper-based design tools in this research. These settings parallel those used in earlier studies and are known to be robust for these purposes [11].

3.1. Protocol analysis

Protocol analysis was first used by Eastman as a means to study design cognition [38]. Since then protocol analysis has mainly been divided into two types such as process-oriented approach and content-oriented approach [39]. Content-oriented approach focuses on information contents of what designers think [40, 41]. Process-oriented approach looks into the procedure of designing, and is mainly used in verbal protocol analysis. Compared to content-oriented approach, scholars can isolate different design behaviors that they want to concern by using process-oriented approach. Being aware of the weakness of concurrent protocol analysis [42, 43], teamwork based protocol analysis has been developed [44]. As collaborators communicate design issues with each other, they verbalize their design thinking. Thus, teamwork based protocol analysis was adopted in this study.

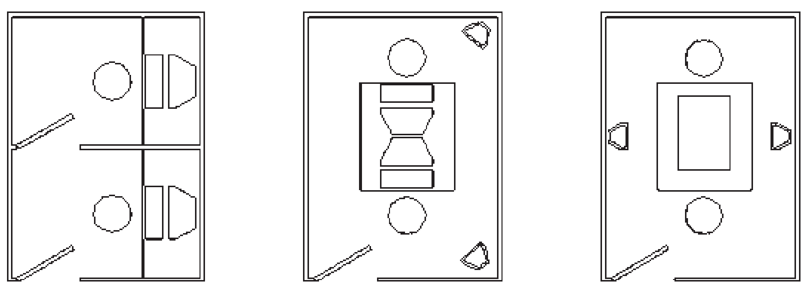
3.2. Experiment design

The experiment has been used in previous studies to examine the efficiency of design learning in different computer supported collaborative settings [11]. This time we adopted one online remote studio setting from the previous studies and developed other two settings, the online co-located and paper based co-located settings. While activity in the online remote is captured by archiving all online activity, the activity in the co-located settings was recorded by digital-cameras set up to capture both verbal and visual data (Table 1). The validity of this methodology adopted has been tested in a pilot study and modified to improve reliability.

	Paper-based co-located	Online remote	Online co-located
Subjects	12 postgraduates	12 postgraduates	12 postgraduates
Design tools	Paper, pencils, rulers, etc.	Hardware: two computers with keyboard and mouse; Software: Microsoft Netmeeting	Hardware: two computers with keyboard and mouse; Software: Microsoft Netmeeting
Communi-cation	Face to Face	Chat line	Face to Face

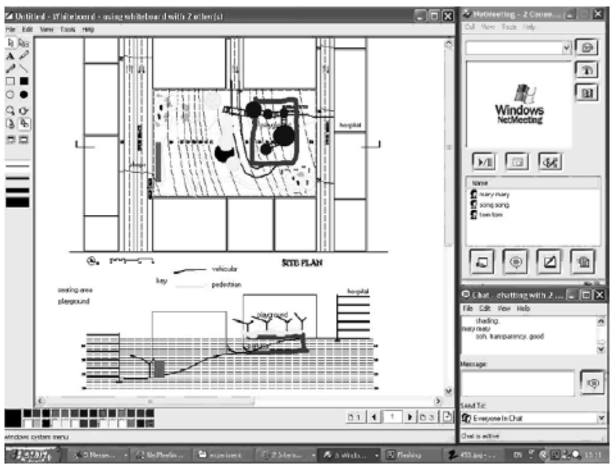
◀ **Table 1. Description of the three settings**

In the online remote setting, subjects are located remote from one another and communicate by chat line while drawing on a shared white board. In the online co-located setting, subjects drew on a shared white board while communicating face-to-face; in the paper-based co-located setting, subjects worked collaboratively on a shared drawing table sitting face-to-face using paper-based design tools. Figure 1 shows the room arrangements and the locations of the cameras for recording co-located activity.



◀ Figure 1. The layouts of the three studio settings and camera positions: oneline remote; online co-located; paper based co-located

The task given to the designers is a site design problem to provide access up a steeply sloping urban park from a bus stop on the lower road to the entrance of hospital on the upper road. The problem is made more complex by requiring a parking area to be accessed from a side road midway up the slope. During the forty minutes design exercise, subjects were asked to think about issues of landscape, playground, car park, and sitting area, etc. while accommodating appropriately sloped pathways. This task is a simple open-ended, "real-world" wicked problem that has been used in previous study [11]. Figure 2 shows an example of a final result in which the initial problem condition can also be observed. In this example the design ideas were developed by using chat-line and Whiteboard.



▶ Figure 2. Example of final result (online remote setting): Whiteboard; Chat-line

Eighteen pairs of postgraduate students joined in this research project. The subjects have been taught architectural design for more than three years in the same educational settings; from previous use of the problem in design studio it is known that they are able to deal with this simple wicked problem in a shared design knowledge domain and can finish the design task within the given time.

3.3. Coding scheme

We adopted Schön's design process consisting of "framing", "moving", and "reflection" as coding scheme and developed the schema by adding some details. "Framing" refers to identify a new design problem or idea, interpret further from design brief; and introduce totally new design ideas or realize totally new design information that has not mentioned before; "moving" refers to produce a tentative solution of this idea or problem; and "reflection" refers to evaluate this solution, that is to "allow the situation to back talk to him (designer)", leading to reframe, retest and re-evaluate; while "null' refers to not relevant to the above three coding scheme (Table 2). The verbal protocol data were encoded according to this coding scheme. It was tested and inter-coder reliability was checked in the pilot study ($r = 0.833$, $\rho = 0.00$), confirming the validity of the coding scheme.

3.4. Application of the coding scheme

As shown above, this coding scheme consists of "framing"(F), "moving"(M), "reflection" (R), and "Null" (N). The transcript presents an example protocol for five minutes in which subjects were designing a car park and a ramp required by the design brief (Table 3). The "framing" activities are shaded with gray color. Through observing the framing process within this five minutes we can see that how subjects develop their proposal of car park and ramp by introducing new ideas and information such as

◀ **Table 2. Coding scheme and examples**

Coding category	Definition	Examples
Framing	Identify a new design problem; interpret further from design brief	We have to provide a sense of arrival at each site access point
Moving	Proposed explanation of problem solving, a tentative solution	Maybe some here can put the playground
Reflection	Evaluate or judge the explanation in 'moving'	I think it is OK. Just represent the design
Null	Not relevant to the above three	Can you see me?

◀ **Table 3. A coding example in online remote setting**

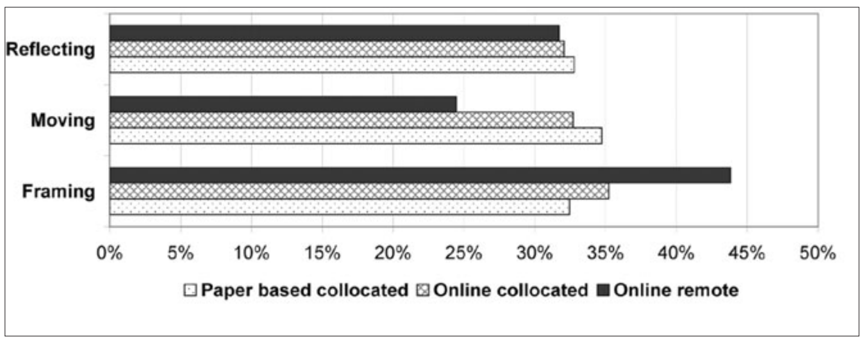
Coding	Transcript A	Transcript B
F		Any winning concepts for the car park?
N	Woo wowo	
F		Underground?
F		What's the concept?
F		Spanish steps in Rome?
N	That's not easy to draw in whiteboards	
F		Ha ha … how to slope down the parking ramp?
N	Yeah?	
R	It doesn't have to go through the whole length rite?	
F/F		Any open structure? Public furniture?
F/R	And then on top of it we can make a court. We got lots of space!	
M		What is the grey line?
M	Grey line is the parking … by cutting into soil and creating an artificial roof on top?	
F	Let's draw out the exact space for a car park for six cars	
R		Yeah, good, hide the cars

"underground", "open structure", and "public furniture", etc. These activities are coded as "framing". The "moving" activities together with digital sketches function as "on-the-spot drawing experiment" helping subjects to test their ideas. The "reflection" thus evaluates the "moving". Three kinds of behavior interact each other, contributing to the framing process.

4. Results

The communication protocols were encoded by counting the number of design exchanges in this "framing-moving-reflection" model and the percentage of those activities calculated (Figure 3). The percentage of

► Figure 3. The percentage of the three design activities across the three settings

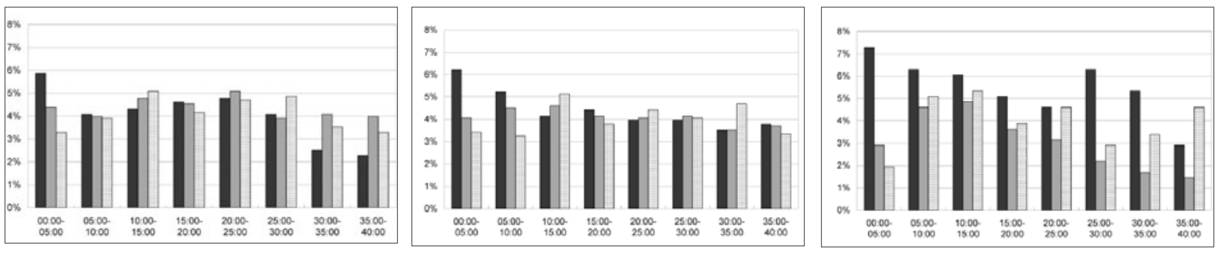


"framing" in online remote setting is 43.8%, higher than that in paper (32.5%) and online co-located settings (35.2%). This finding correlates with findings in previous studies that low-band width (chat line) affords more design exploration than high-band width (e.g. face to face) [11].

4.1. "Framing-moving-reflection' in three settings

We calculated the percentage of the three actions of framing, moving and reflecting in five-minute intervals for the whole design exercise. A summary of results is presented in Figure 4. In both co-located settings, the distributions of the three actions appear to be equally represented, while in remote setting framing activities are more dominant than other two activities, an interpretation supported by the results of ANOVA test (Table 4.). The frequency of these three activities are not significantly different in paper (F (1,14) = 0.27, p=0.77) and online co-located settings (F (1,14) =0.74, p=0.49), while we observe a significant difference in the remote setting (F (1,14) = 7.61, p(0.01).

▼ Figure 4. The distribution of "framing-moving-reflection": paper-based; online co-located; remote



4.2. "Framing-moving-reflection" across three settings

We isolated percentage of framing-moving-reflection activities in five minutes interval for the whole design exercise and compared those activities across the three settings. Figure 5 shows the distribution of framing-moving-reflection process across the three settings. This result suggests that the online remote setting supports framing better than both co-located settings. These findings are further supported by one way

	Paper co-located	Online co-loated	Online remote
F (framing-moving-reflection)	0.27	0.74	7.61
p	0.77	0.49	<0.01

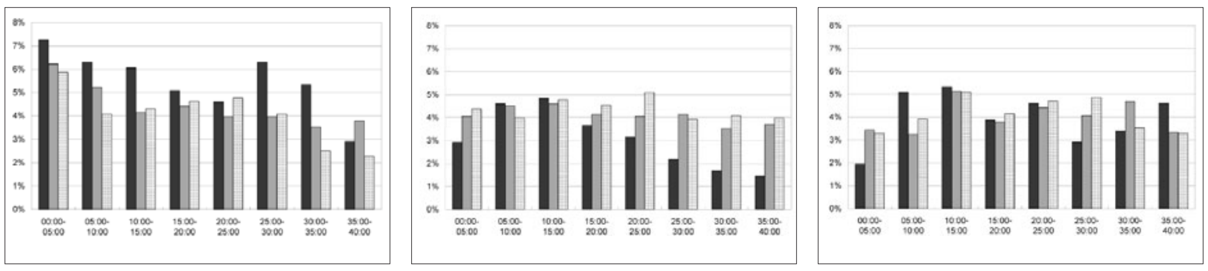
◀ **Table 4. Results of ANOVA-test on the distribution of the three activities in each setting**

	Online remote vs. Online	Online co-located vs. Paper	Paper co-loated vs. Online
F (Framing)	42.83	0.22	26.49
p	<0.001	0.64	<0.001
F (Moving)	197.74	17.73	257.44
p	<0.001	<0.001	<0.001
F (Reflection)	77.46	3.49	97.06
p	<0.001	0.0829	<0.001

◀ **Table 5. Results of ANOVA-test on the distribution of the three design activities**

ANOVA-test (Table 5). The average distribution of "framing" is significantly different between the online remote and online co-located settings ($F(1,14) = 42.83$, $p(0.001)$), and similarly between paper based co-located and online remote settings ($F(1,14) = 26.49$, $p(0.001)$); no significant difference is found when comparing online co-located and paper based co-located settings ($F(1,14) = 0.22$, $p = 0.64$).

▼ Figure 5. The distribution of the three activities across the three settings: framing; moving;reflection



5. Discussion and conclusion

Digital tools are used increasingly in studio teaching. Problem framing is correlated to learning. If the use of chat line increases the proportion of framing activities, what are the implications of these results for design learning? Do digital design tools benefit designers beyond automation of repetitive tasks?

5.1. Discussion

Importantly, this experiment demonstrates that using digital design tools does not interrupt the design conversation, suggesting that the preconception of digital tools interrupting the design conversation is unfounded, at least in so far as the conversation is measured as a framing process. The results also suggest that the medium has some influence on the activity of problem framing.

This and earlier studies together suggest that tools that facilitate multiple representations such as diagrams, text, and models can enhance students' design learning in a number of ways [45, 46]. It would appear from this study that digital tools belong in the category of tools that contribute to the process of design and should not be relegated to a role of supporting 'hard lining' and presentation after design thinking is completed. The positive effect observed here in the non-co-located setting continues to surprise the researchers as it is counter-intuitive and is not supported by the lore of designing, deserving further consideration.

That modes of representation affect designing has been examined elsewhere and several indications are that digital design opens up new and positive possibilities. Kvan, Wong et al. [47] identified the value of engaging in multiple representations during design learning and concluded that structural activities with multiple representations including text, diagram, and model support better learning. Perhaps the increased framing observed here is a contributor to the challenge of using digital tools to fundamentally change methods of design.

Some caveats deserve mention. In these experiments, the activities of "framing", "moving" and "reflection" took place in a context that may be somewhat different to that of daily practice. In the remote setting, subjects used a chat-line to communicate their design ideas and whiteboard to share their on-the-spot explorations [12], thus the activities of "framing", "moving", and "reflection" therefore are differentiated by the medium they adopted in different settings. The design process appears to be more structured in this experimental context than that more commonly encountered in the messy settings of design practice.

5.2. Conclusion

Even with such caveats, we may draw some initial conclusions or identify opportunities for further research. Earlier studies have noted that chat line conditions are characterized by the introduction of more new ideas and that less fixation is observed. This may be correlated to the higher frequency of framing in the chat line condition noted in this experiment. Co-located environments are popular in design education and practice, especially where practices are separated by several time zones; such conditions or work need appropriate tools to support designing in these settings. The implications of these findings should not be interpreted only in the design of digital tools but considered also in non-digital contexts. We may also consider the processes undertaken in design activities in co-located settings. It could be that traditional studio tasks need to be redefined to include non-co-located activities in order to promote particular problem framing opportunities or that we need to find ways of realizing benefits in co-located digital work, for example by working through chat media. We need also to investigate whether the difference in problem framing activity correlates to learning. It is possible, for example, that the increased problem framing scaffolds design learning. To do that, we need to examine why more framing occurred in distal activities in these experimental conditions.

Acknowledgements

Recognition is given to the students who participated in this research project, the University of Hong Kong for its funding and to the members of Research Group of Architecture Department, the University of Hong Kong who gave invaluable comments on early drafts. The authors also would like to thank the anonymous reviewers who helped us to strengthen our paper.

References

1. Rowe, P. G., *Design Thinking*, MIT Press, Cambridge, MA, 1987.
2. Rittel, H. W. J. and Webber, M., Dilemma in a General Theory of Planning, Policy *Sciences*, 1973, **4**, pp. 155–160.
3. Churchman, C. W., Wicked Problems, *Management Science*, 1967, **14**, pp. B141–B142.
4. Asimow, M., *Introduction to Design*, Prentice-Hall, Englewood Cliffs, New Jersey, 1962.
5. Simon, H. A., *The Sciences of the Artificial*, MIT Press, Cambridge, MA, 1996.
6. Schön, D. A., Problems, Frames and Perspectives on Designing, *Design Studies*, 1984, **5**, pp. 132–136.
7. Goldschmidt, G., The Dialectics of Sketching, *Creativity Research Journal*, 1991, **4**, pp. 123–134.
8. Schön, D. A. and Wiggins, G., Kinds of Seeing and Their Functions in Designing, *Design Studies*, 1992, **13**, pp. 135–156.
9. Eisenman, P., 'Visions Unfolding: Architecture in the Age of Electronic Media, Nesbitt, K. ed., *Theorizing a New Agenda for Architecture: An Anthology of Architectural Theory 1965–1995*, Princeton Architectural Press, New York, NY, 1996.
10. Corona-Martinez, A. and Quantrill, M., *The Architectural Project*, Texas A & M University Press, 2003.
11. Kvan, T., Vera, A. and West, R., Expert and Situated Actions in Collaborative Design, in: Siriruchatapong, P., Z. Lin and J.-P. Barthes eds., *Proceedings of second international workshop on CSCW in design*, International Academic Publishers, Beijing, 1997, pp. 400–405.
12. Schön, D. A., *The Design Studio: An Exploration of Its Traditions & Potential*, RIBA Publications Limited, London, 1985.
13. Mitchell, W. J., *The Logic of Architecture: Design, Computation and Cognition*, The MIT Press, Cambridge, MA, London, England, 1994.
14. Buchanan, R., Wicked Problems in Design Thinking, Margolin, V. and R. Buchanan eds., *The Idea of Design*, MIT Press, Cambridge. MA, 1995.

15. Goldschmidt, G., Problem Representation Versus Domain of Solution in Architectural Design Teaching, *Journal of Architectural and Planning Research*, 1989, **6**, pp. 204–215.

16. Kolodner, J. L. and Wills, L. M., Powers of Observation in Creative Design, *Design Studies*, 1996, **17**, pp. 385–416.

17. Cross, N. and Cross, A. C., Expertise in Engineering Design, *Research in Engineering Design-Theory Applications and Concurrent Engineering*, 1998, **10**, pp. 141–149.

18. Cross, N., Natural Intelligence in Design, *Design Studies*, 1999, **20**, pp. 25–39.

19. Geol, V. and Pirolli, P., The Structure of Design Problem Spaces, *Cognitive Science*, 1992, **16**, pp. 395–429.

20. Cross, N., Design Cognition: Results from Protocol and Other Empirical Studies of Design Activity, Eastman, C. M., W. M. McCracken and W. C. Newstetter eds., *Design Knowing and Learning Cognition in Design Education* Elsevier Science Ltd, Oxford, 2001.

21. Cross, N., Expertise in Design: An Overview, *Design Studies*, 2004, **25**, pp. 427–441.

22. Schön, D. A., *The Reflective Practitioner: How Professionals Think in Action*, Basic Books Inc., New York, 1983.

23. Dewey, J., *How We Think – a Restatement of the Relation of Reflective Thinking to the Educative Process*, Boston, 1933.

24. Argyris, C., *Knowledge for Action: A Guide to Overcoming Barriers to Organizational Change*, Jossey-Bass, San Francisco, CA, 1993.

25. Smith, M. K., Donald Schön: Learning, Reflection and Change, www.infed.org/thinkers/et-schon.htm, July 14, 2002.

26. Schön, D. A., The Theory of Inquiry: Dewey'S Legacy to Education, *Curriculum Inquiry*, 1992, p. 22.

27. Sachs, A., 'Stuckness' in the Design Studio, *Design Studies*, 1999, **20**, pp. 195–209.

28. Kvan, T., Learning through Structural Activity in Collaborative Computer Aided Design, in: *Proceedings of the Seventh Conference on Computer Aided Architectural Design Research in Asia, CAADRIA '02*, Multimedia University, Cyberjaya, Malaysia,, 2002.

29. Sellen, A. J. and Harper, R., *The Myth of the Paperless Office*, MIT Press, Cambridge, MA, 2001.

30. Wigley, M., Paper, Scissors, Blur, Zegher, M. C. d. and M. Wigley eds., *The Activist Drawing: Retracing Situationist Architectures from Constant's New Babylon to Beyond* Drawing Center; MIT Press, New York: Cambridge, MA; London, 2001.

31. Robbins, E., *Why Architects Draw*, MIT Press, Cambridge, MA, 1994.

32. Lawson, B., *Design in Mind*, Butterworth-Heinemann Ltd., Oxford, 1994.

33. Gabriel, G. and Maher, M. L., Analysis of Design Communication with and without Computer Mediation, in: *Proceedings of Co-designing 2000*, 2000, pp. 329–337.

34. Schnabel, M. A. and Kvan, T., Spatial Understanding in Immersive Virtual Environments, *International Journal of Architectural Computing*, 2003, 1.

35. Kock, N., Can a Leaner Medium Foster Better Group Outcomes? A Study of Computer-Supported Process Improvement Groups, Khosrowpour, M. ed., *Effective Utilization and Management of Emerging Information Technologies* Idea Group Publishing, 1998.

36. Lahti, H., Seitamaa-Hakkarainen, P. and Hakkarainen, K., Collaboration Patterns in Computer Supported Collaborative Designing, *Design Studies*, 2004, **25**, pp. 35–371.

37. Puntambekar, S., Nagel, K., Hübscher, R., Guzdial, M. and Kolodner, J. L., Intra-Group and Intergroup: An Exploration of Learning with Complementary Collaboration Tools, in: Enyedy, R. H. N. M. N. ed., *Proceedings of Computer Supported Collaborative Learning '97 (CSCL'97)*, 1997, pp. 207–214.

38. Eastman, C. M., *Explorations of the Cognitive Processes in Design*, Department of computer science report, Carnegie Mellon University, Pittsburgh, 1968.

39. Dorst, K. and Dijkhuis, J., Comparing Paradigms for Describing Design Activity, *Design Studies*, 1995, **16**, pp. 261–274.

40. Suwa, M. and Tversky, B., What Architects See in Their Sketches: Implications for Design Tools, in: *Conference on Human Factors and Computing Systems*, ACM Press, Vancouver, British Columbia, Canada, 1996, pp. 191–192.

41. Kavakli, M. and Gero, J. S., Sketching as Mental Imagery Processing, *Design Studies*, 2001, **22**, pp. 347–364.

42. Lloyd, P., Lawson, B. and Scott, P., Can Concurrent Verbalization Reveal Design Cognition?, *Design Studies*, 1995, **16**, pp. 237–259.

43. Mitchell, W. J., Cad as a Social Process, in: Tan, M. and R. Teh eds., *The Global Design Studio*, Centre for Advanced Studies in Architecture National University of Singapore, Singapore, 1995, pp. 7–10.

44. Dorst, K., Analysing Design Activity: New Directions in Protocol Analysis, *Design Studies*, 1995, **16**, pp. 139–142.

45. Kvan, T., Yip, W. H. and Vera, A., Supporting Design Studio Learning: An Investigation into Design Communication in Computer-Supported Collaboration, in: *CSCL'99*, Stanford University, 1999, pp. 328–332.

46. Kvan, T., Wong, J. T. H. and Vera, A. H., Supporting Structural Activities in Design: A Multiple-Case Study, in: Chan, A., S. Chan, V. L. Hong and V. Ng eds., *Proceedings of Fifth International Conference on Computer Supported Cooperative Work in Design (CSCWD2000)*, Hong Kong Polytechnic University, Hong Kong, 2000, pp. 116–120.

47. Kvan, T., Wong, J. T. H. and Vera, A., The Contribution of Structural Activities to Successful Design, *International Journal of Computer Applications in Technology*, 2003, **16**(2/3), pp. 122–126.

Thomas Kvan and Song Gao
The University of Hong Kong,
Hong Kong, SAR, P. R. China

tkvan@arch.khu.hk, sgao@arch.khu.hk

Assessment of the Use of 3D-Viewing and Mark-up Tool for Rich Network Design Communication

Mitsuo Morozumi and Riken Homma